The SIM Astrometric Reference Grid

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What is SIM?

SIM is a space-based interferometer with the capability to precisely measure the astrometric positions, proper motions, and parallaxes of optical sources.

A subset of SIM science goals:

- Improve on Hipparcos stellar positions by 2 orders of magnitude and extend knowledge to fainter stars
- Search for other planetary systems by surveying 1000 nearby stars
- Study dynamics and evolution of stellar clusters
- Calibrate luminosity distance ladder

SIM Space Interferometry Mission

A NASA Origins Mission

Portrait of the Instrument

SIM

Space Interferometry Mission

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SIM Astrometric Measurement

Space Interferometry Mission

SIM

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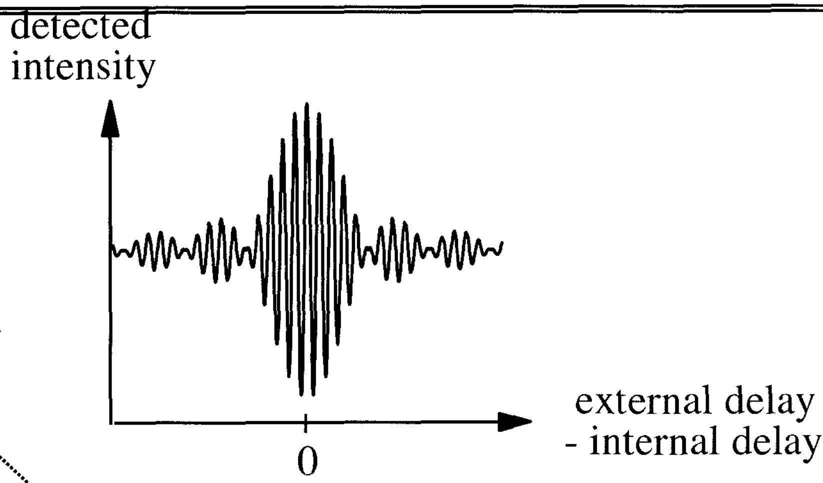
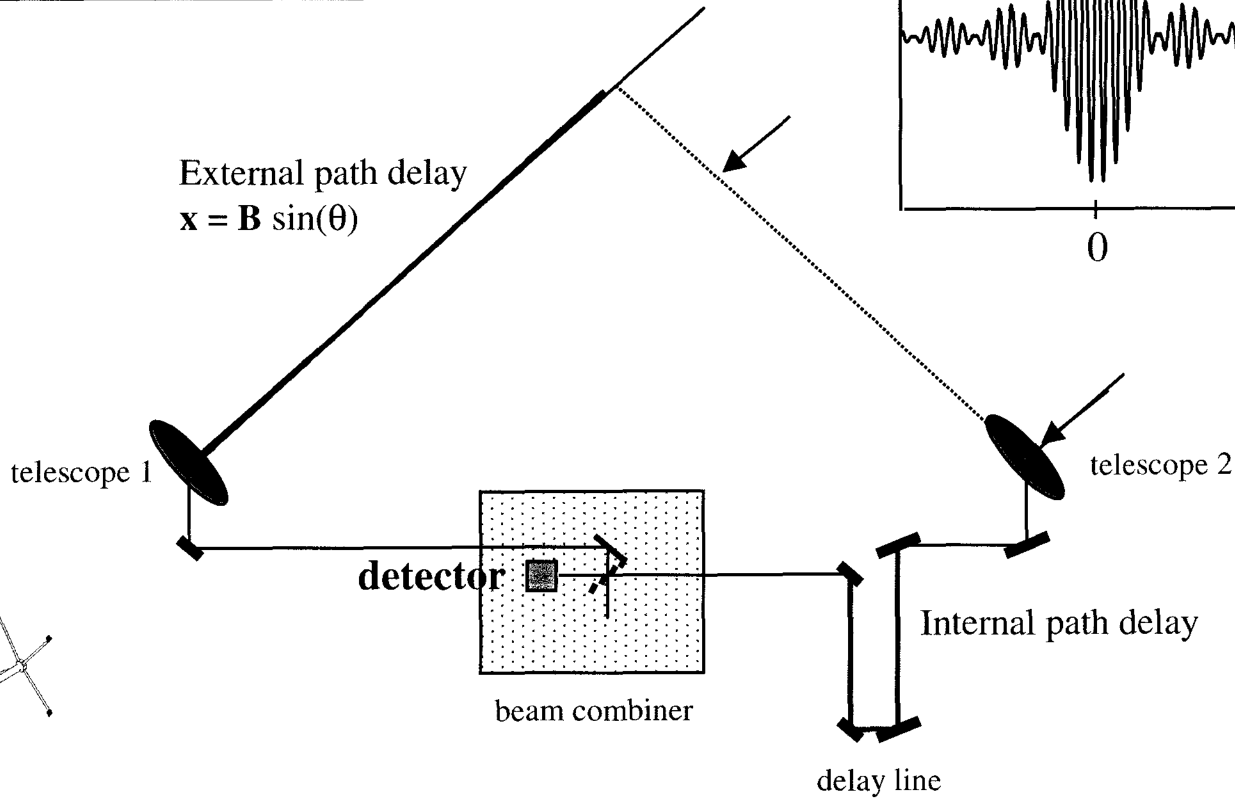
The Astrometric Equation

$$d = s \bullet B + C + errors$$





The peak of the interference pattern occurs when the internal path delay equals the external path delay

Space Interferometry Mission

SIM

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Primary Goal

Achieve a 4 μas wide-angle (1 μas narrow-angle) 4π astrometric grid to act as a global instrument calibration and a set of "surveyor's points" for science measurements

Standard Scientific Problem: Using our uncalibrated instrument to measure not-sufficiently-known quantities to perform a precise instrument calibration.

By having a set of standard "surveyor's points" on the sky, we can use these points to determine spacecraft orientation and baseline length for each set of observations.

Why A Grid?

Some basic design characteristics of SIM:

- Observations limited to 15° field-of-regard without reorienting spacecraft
- Attitude control system does not give instrument baseline orientation precisely enough for required science precision (need 100 μas)
- 60° Solar exclusion angle
- Measurements are all one-dimensional *optical path delays*
- System tracks metrology (baseline length and optical path lengths) changes from an initial *unknown* value

Accumulating Grid Observations

Space Interferometry Mission

SIM

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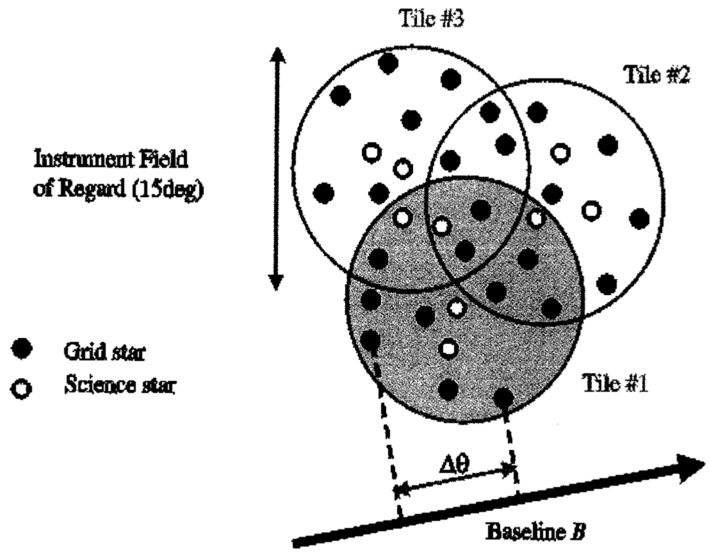

- O(3000) Stable Astrometric Objects
- Individual Measurements are 1-d delays, *not separations*
- About 1/2 tile offset
- ~1000 total 15° tiles per scan (solar exclusion of 60°)
- ~12-15 grid objects per tile
- Scan the whole sky (minus solar exclusion) ~4.5 times/year

→ Common Baseline Orientation during a tile ties delay measurements together for that tile

→ Objects in tile overlap regions tie adjacent tiles together for the 4π Grid

→ Celestial Sphere surveyed twice per scan with Orthogonal Baseline Projections to obtain Isotropic Position Errors.

→ Simultaneous fit of instrument and stellar parameters. This resulting Grid Catalog will then be used as instrument calibration during science observations

Solving The Grid

We are currently simulating the grid with a Monte Carlo grid catalog and a simple instrument model to make instrument design decisions.

- The nominal 5 year mission will generate 23k tiles & 300k observations
- The resulting design matrix is sparse (1% filled) and large (343k x 100k)
- For our current simulations of the grid, we solve it using the method of Conjugate Gradients on the Normal Equations, looking at the difference vector between a parameter-based model and the measurements.
- The solution takes ~8 hours on a Sun Ultra 30 workstation
  - Some parts of the process operate in parallel on a farm of ~20 workstations

Grid Object Requirements

- Sufficient stars for grid
- Small enough angular diameter to remain unresolved
- Bright enough to be observed quickly
- Astrometric Stability
  - Large starspots
  - Binaries
  - Ground knowledge

At first, two populations seem to fit these requirements

- Close (60 pc) G dwarfs
- Farther (1kpc) K giants

SIM Grid Candidate Populations

G dwarfs

- 9th magnitude @ 60 pc
  - 1000 - 1500 stars
  - Starspots not an issue
  - Need radial velocity measurements of 1 (10) m/s to detect Jupiter (Neptune) at 2 AU.
- 12th magnitude
  - enough for full grid
  - could measure 4-40 m/s radial velocity, but larger distance means Neptunes stop being an issue.
  - Would need close proxy sample to understand contamination fraction

K giants

- 12th magnitude reaches 5 kpc (but 1kpc is more representative)
  - enough stars for the whole grid
  - More massive stars & larger distance means there is less sensitivity to wobble from planet-sized companions.
  - Conversely, since these stars are farther away, it is more difficult to measure for close stellar companions with prior ground-based measurements, so ground-work is harder
  - More surface convection
  - More likely to have large starspots, but distance means less problem from them
  - Need close proxy sample to study populations

The Road Ahead

- Observational programs are currently operating to identify K giant Grid candidates in both hemispheres
- Simulation using detailed instrument models
  - Observations Scenarios
  - Effects of Instrument design decisions
  - Grid contamination effects